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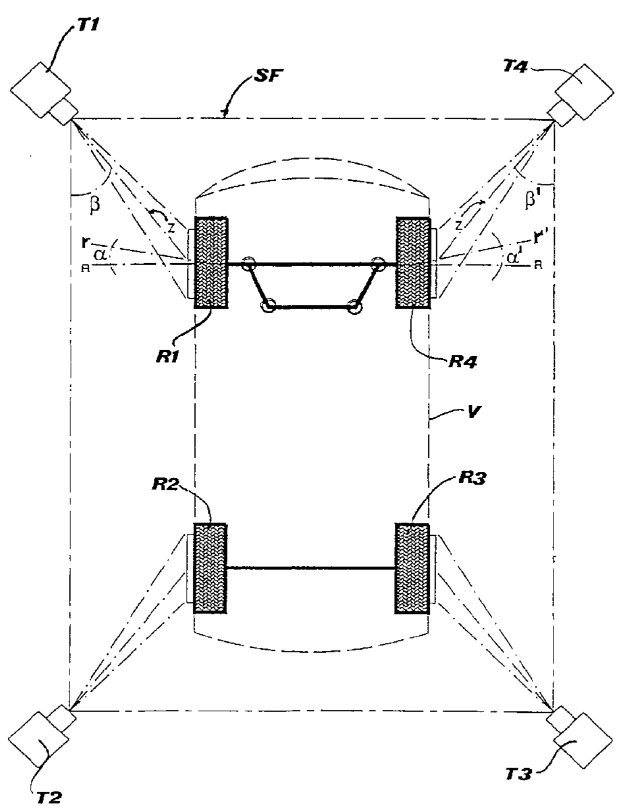
**(54) Title:** METHOD AND APPARATUS FOR MEASURING THE SET-UP ANGLES OF A MOTOR VEHICLE, IN PARTICULAR THE TOE-IN AND CAMBER ANGLES OF THE WHEELS




**(57) Abstract:** Method for checking the set-up of the suspension of motor vehicles, in particular for measuring the total toe-in and camber angles of the wheels. Two or preferably four videocameras in predetermined fixed positions are used, said videocameras being able to define a fixed spatial reference system, each videocamera being associated with a respective wheel. The method comprises the steps of: identifying, for each wheel, its profile projected onto the optical sensor plane of the respective videocamera, as the locus of the points of greatest variation in luminous intensity; calculating mathematically, using the least square fit method, the conic section which best approximates the profile thus obtained; calculating, from the equation of this conic section and from the known coordinates of the position of the videocameras in the fixed spatial system, the two angles which define - with respect to a vertical longitudinal plane and with respect to a horizontal plane - the orientation of a bundle of parallel planes which intersect, in the form of a set of circles, the cone obtained projecting into space the conic section "viewed" by the videocamera, these angles representing the total toe-in and the camber of the wheel, respectively.

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METHOD AND APPARATUS FOR MEASURING THE SET-UP ANGLES OF A MOTOR VEHICLE, IN PARTICULAR THE TOE-IN AND CAMBER ANGLES OF THE WHEELS

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The present invention relates to an apparatus for checking the set-up angles of a motor vehicle, in particular for measuring the toe-in and camber angles of the associated wheels.

It is known that the set-up angles of a motor vehicle, in particular, as mentioned, the toe-in and camber angles of the wheels, determine not only the wear of the tyres, but also the behaviour of the vehicle itself on the road, both as regards the so-called "road-holding" performance and the travel comfort. The importance of carrying out frequently an accurate check as to the correctness of these set-up angles is therefore obvious.

The toe-in and camber angles of a wheel of a motor vehicle are the angles formed by the wheel axis - or by a plane perpendicular to this axis and passing through the centre of the wheel, conventionally called "wheel plane" - with respect to a reference system fixed to the bodywork of the vehicle itself. More precisely, the toe-in angle is the angle formed by the wheel axis with respect to a vertical plane passing through the centre thereof and perpendicular to the longitudinal axis of the vehicle, or, in an equivalent manner, the angle formed by the wheel plane with respect to a vertical plane passing through the longitudinal axis of the vehicle. The camber angle, on the other hand, is the angle formed by the wheel axis with respect to a horizontal plane passing through the centre thereof or, in an equivalent manner, the angle formed by the wheel plane with respect to a horizontal plane passing through the longitudinal axis of the vehicle.

The most conventional methods for checking these set-up angles are based on measurements determined by detecting instruments applied and fixed to the individual wheels. The main drawbacks of these methods arise precisely from the fact of having to use detecting instruments fixed to the wheels, this resulting, for example, in the problems or drawbacks listed below:

1. Mechanical assembly precision: possible errors during fixing of the instruments result in major measurement errors. Moreover, because of the precision required, whenever measurement must be performed, a significant portion of the testing time is used for this preliminary operation;

2. Stable fixing: the instrument for detecting the measurement point

must be fixed very firmly because, otherwise, it may be displaced during measurement and result in further errors;

3. Systematic errors during measurement: in view of the risk that the reference point on wheel may not be chosen in a sufficiently accurate manner, errors in measurement which cannot easily be controlled may arise;

4. Handling of the instruments: the instruments to be fitted must be light, so that they can be easily handled, but at the same time robust to take account of the environment in which they are used.

In order to overcome these problems, more modern methods for measuring the set-up angles have already been proposed, said methods being based on the use of measuring means which are opto-electronic and therefore do not make contact with the wheels of the vehicle or with the vehicle itself. Measuring methods of this type have been proposed, for example, in DE-A-2948573, US-A-4,899,218 and EP-A2-0,895,056.

DE-A-2948573, dating back to 1979, describes the general principles of such a measuring method which, from a conceptual point of view, is relatively simple, i.e. it consists in using videocameras for detecting the profile of the wheels, this profile consisting - due to the fact that the plane of each wheel is not perpendicular to the axis of the videocamera detecting it - of an ellipse. The greater axis and the smaller axis of this ellipse, as well as the point of intersection of these axes, are then determined and from these it is then possible to obtain, mathematically, the orientation of the wheel plane with respect to the longitudinal axis of the vehicle.

This general principle, however, gives rise to major problems regarding practical implementation of the invention, in particular at least the following two main problems:

a) Definition of the profile of the ellipse: according to DE-A-29 48 573, an electronic evaluation of the elliptical image of a circle associated with the external diameter of the wheel rim or a circle associated and concentric with the rim is performed. From this elliptical image, which is formed on the sensor layer of the videocamera recording tube, which receives the light, five points (or two points and two tangents, according to the equivalent variant described in the same patent) are chosen, said points determining - as is known in geometry - the mathematical equation of the ellipse. Since in DE-A-29 48 573 no indication as to the manner in which the five points which determine the ellipse is given, it must be considered

that the choice thereof is random in nature. The method proposed here, however, is subject to a high degree of imprecision such as to render it unusable in practice: in fact, on the one hand, owing to the inevitable imperfect circularity of the rim, in particular when the rim is no longer new, but worn or damaged by impacts, and on the other hand due to the fact that the image of the rim on the optical receiving layer of the videocamera is not formed by a pure line, but by a bundle of adjacent lines (and here it must be noted that the enlargement of the image proposed according to the variant in Fig. 7 of DE-A-29 48 573 worsens the accuracy of definition of the point instead of improving it), the random choice of five points may result in the calculation of ellipses which are also very different from the theoretical one, and hence major errors in measurement.

b) Definition of the position of the wheel: once the profile of the ellipse, as well as its greater and smaller diameters, have been determined, it is possible to determine mathematically the angular orientation of the plane containing the ellipse with respect to the axis of the videocamera. This angular orientation - in addition to being subject to the major errors in measurement mentioned above - still does not precisely define the plane of the wheel, but instead a bundle of planes which are parallel to each other and only one of which must be taken as a reference for the wheel plane. In order to determine precisely this reference plane and consequently determine the orientation thereof, not with respect to the axis of the videocamera, but instead with respect to the longitudinal axis of the vehicle, DE-A-29 48 573 further proposes using one videocamera for each wheel, displaceable into two different positions, in order to obtain two elliptical images of the same rim. It is obvious, in connection with that stated above, that these two images therefore define the same bundle of parallel planes, but with two different angular orientations compared to the differently positioned axes of a first videocamera and a second videocamera, respectively. Since, together with the elliptical profile, the centre of the ellipse is determined, it is obvious that the reference plane for the position of the wheel will be determined precisely as the plane in which the two centres of the respective ellipses coincide. This procedural method is however subject - doubly so - to the abovementioned drawbacks: on the one hand, because both the elliptical images may produce measurement errors which in this case are accumulated and, on the other hand, because other measurement errors may result from a not perfectly controlled movement of the detecting videocamera.

US-A-4,899,218 describes a measuring process based on the projection of

a light beam with an oscillating structure onto the wheel so as to produce at least two reference images thereon; these images are read by video cameras positioned at a certain angle with respect to the optical plane defined by the plane of oscillation of the beam. The spatial position of the lines, and hence the wheel, is calculated by a processor using a known triangulation system.

EP-A2-0,895,056 describes a measuring method and apparatus consisting in obtaining a certain number of pairs of images of each wheel as the vehicle is moving towards the measurement position. The apparatus uses two video cameras for each wheel, having their lenses directed towards the measurement position and stably connected to the latter. The video cameras are connected to a processor able to process the images of each wheel viewed by them, so as to determine the spatial position of the rim by examining the circular-structure images and identifying the regions in which the transition between different grey levels is maximum, and use these images to calculate the characteristic set-up angles. It is also possible to detect any wobble of the rim edge, i.e. non-perpendicularity of the wheel plane with respect to the associated axis of rotation.

All these known devices, however, are relatively complex with regard to both their manufacture and their preparation; in particular the principle of detecting and comparing a pair of elliptical images of the same wheel involves the use of two videocameras - or a displaceable videocamera - for each wheel, this complicating the installation and the associated management software and resulting in relatively high costs. On the other hand, despite this complexity, the accuracy of measurement of these known devices is still too low, to the extent that these known devices do not appear to have actually found a practical application - at least hitherto.

The object of the present invention is therefore to propose a measuring system of the contactless type, for detecting the characteristic set-up angles of the wheels of a vehicle, able to overcome these problems and ensure that the measuring operation may be performed easily and rapidly.

More precisely, the primary aim of the invention is to propose a measuring method which, based on the general principles illustrated in DE-A-29 48 573, is able to provide extremely precise information as to the angular orientation of the plane of the wheels with respect to a fixed spatial reference system which is outside the vehicle and not fixed thereto and with respect to which the vehicle can therefore be arranged with a variable angular orientation. This aim is achieved by

means of the characteristic features highlighted in particular in Claim 1.

In other words, the invention thus defined differs from the prior art fundamentally for two reasons:

- on the one hand, owing to the fact that the conic equation which corresponds to the profile of the wheel rim is not determined by means of simple - almost random - choice of the number of points of this profile necessary and sufficient for mathematical determination of a conic section, but instead by means of a method - defined briefly below as "repeated approximation" method - which allows a selection and repeated filtering of a redundant number of points, until the conic section which best approximates the true profile is determined;

- on the other hand - at least in a preferred simplified embodiment of the invention - the sole information relating to the profiles of only two opposite wheels of the motor vehicle is used.

The Applicant has in fact established that such a method of repeated approximation - an example of which is the least square fit method, known in mathematics - allows definition of the conic section which corresponds to the wheel profile with a degree of accuracy sufficient for this conic section to be utilisable for the consequent measurement of the set-up angles of a motor vehicle.

The Applicant has also established that the information obtained on the basis of the preferred simplified embodiment of the invention, without further elements, is already sufficient for determining those set-up angles, such as:

- the total toe-in of a pair of wheels (front or rear), which corresponds to the algebraic sum of the toe-in angles of the individual wheels and which may be determined without any reference to the vehicle, but only from the measurement of the angles which the planes containing the wheels form with respect to each other, or with respect to a fixed reference system however defined; and

- the camber of a wheel, which corresponds to the angle formed by the wheel plane with respect to the horizontal plane on which the vehicle rests and which may be determined in turn without any reference to the vehicle, but only with respect to the fixed reference system, in the case (still considered implicitly valid in measurements performed using the existing contact systems) where the vehicle is resting on the horizontal surface of the workshop.

These measurements are those most frequently used in practice in order to define with sufficient accuracy the set-up of the vehicle. In other words, if the measurement is limited to only the main set-up angles, such as total toe-in and

camber, the invention proposes a simplified and inexpensive system based on a measuring method which is in principle much simpler than those proposed by the prior art.

Moreover, an important additional aim of the invention is to propose a measuring method which, without making the installation more complex, nevertheless allows, when desired, also the measurement of all the set-up angles of the vehicle, i.e. is able to provide also information - which is equally very precise - concerning the angular orientation of the plane of the individual wheels and their position with respect to the longitudinal axis of the vehicle. This aim is achieved by means of the characteristic features mentioned in Claim 2.

The Applicant has in fact established that this information and the further determination of the position of the vehicle with respect to the fixed spatial reference system is necessary when it is required to detect:

- the toe-in of each individual wheel separately;

- the steering angles;

- the thrust axis, or the axis obtained as the vectorial sum of the toe-in values of the individual wheels, the characteristic angle of which is defined using the geometric axis of the vehicle as the reference axis;

- the axis of symmetry, i.e. the difference between the toe-in values of the individual wheels; and

- the set-back angle, i.e. the angle formed by the axis which joins the right-hand and left-hand wheels with an axis perpendicular to the axis of symmetry of the car;

i.e. measurements which are necessary in particular during initial testing of a new vehicle in the factory.

Further characteristic features and advantages of the invention will emerge, however, more clearly from the following detailed description of a preferred embodiment, provided purely by way of example, also with reference to the accompanying drawings, in which the sole figure is a plan view diagram of a motor vehicle arranged inside a fixed measuring system.

As shown, in a preferred embodiment, according to the invention, a spatial reference system is used, said system consisting of fixed quadrilateral SF situated outside the vehicle V and not fixed thereto and taking the physical form of four fixed videocameras T1, T2, T3 and T4, i.e. one for each of the wheels R1, R2, R3 and R4; these videocameras are arranged so as to record the respective wheels of

the vehicle V in a manner which is not exactly in front of the wheel, but from a certain angle. This arrangement of four videocameras must be regarded as a purely non-limiting example of the invention since it is certainly possible, in smaller installations and for cost-related reasons, to use an arrangement comprising only two videocameras, to be used in each case in correspondence of the two opposite wheels of the same axle of a motor vehicle.

1) Measurement of the total toe-in and camber

As already mentioned, firstly the total toe-in and the camber are measured, i.e. the sums of the angles $\alpha$, $\alpha'$ (shown on a much larger scale than in reality for the sake of clarity of the drawing) formed by the axes r, r' of the opposite wheels with respect to a vertical plane R-R, passing through the centre of the wheels and therefore transverse, respectively, with respect to the vehicle and with respect to the horizontal plane (to be imagined as coinciding with the plane of the drawing) on which the wheels rest.

The measurement process envisages determining a set of measuring points on the wheel and the angular orientation of the planes of the wheels with respect to the fixed spatial reference system and comprises at least the following main steps:

a) each videocamera, located so as to view the respective wheel not frontally, but at a certain angle $\beta$, $\beta'$, as already mentioned, is used to read the profile of the wheel rim; this profile is determined as the locus of the points of maximum difference in luminous contrast, occurring at the transition points from the rim to the tyre. The image recorded by the videocamera is digitalized and converted into a rectangular matrix of intensity values, one for each digitalized point. This matrix of values is equalized, namely multiplied by a special factor automatically calculated in relation to the average luminosity of the image. The purpose of the equalization is to reduce the effect of the variation in the lighting conditions of the object. A suitable mathematical operator (Laplace, Sobel) is applied to the equalized values in order to obtain a new matrix of values, one for each point sampled, where the values represent the gradient of variation in intensity. This gradient has a locally very high value at points which, as mentioned, correspond to the rim-wheel interface. A threshold operator is then used in order to extract from the image, only those points for which the gradient is sufficiently high, and among these points there is certainly the rim-tyre interface. The binary matrix obtained is filtered using an erosion operator, in order to eliminate all the isolated points (noise)

and leave only the points belonging to predetermined geometric groups (lines, circles, etc.). In order to improve the image quality and reduce the effect caused by the ambient lighting variable, the vehicle wheel is illuminated with infrared light using a set of emitting diodes, and an infrared filter having spectral characteristics coinciding exactly with the emission spectrum of the infrared diodes is placed in front of the optical system of the videocamera: the artificial ambient lighting is completely filtered and its negative effect on the quality of the measurement is thus eliminated. A small influence caused by the infrared fraction of the solar light which may pass through the filter remains, but normally this influence is not significant in the definition of the measurement. By way of further reduction of the effect of the ambient lighting it is also possible to obtain the image to be processed as the difference between the images detected with the infrared lighting switched on and with the infrared lighting switched off, respectively.

b) Once a bundle of points sufficiently close to a conic line is obtained, the measuring method according to the invention must use the redundancy available in the data in order to be able to compensate for errors and imperfections in the image. The calculation of the reference conic section must namely use the greatest possible amount of information obtained from the image in order to reduce the effect of damage to the rim, imperfect detection of the image, imperfect lighting conditions, etc., and obtain the "best" conic section - i.e. the conic section which best approximates the true profile - using data analysis methods which extract this information, eliminating the imperfections as far as possible. One of the methods which can be used for this purpose is the least square fit method. More precisely, a pair of coordinates ( x, y ) corresponding to the position of the point in the image plane is assigned to each point determined in the preceding operation. The equation conic is identified as follows:

$$a_{11}\, x^2 + 2{*}a_{12}\, x\, y + a_{22}\, y^2 + 2{*}a_{13}\, x + 2{*}a_{23}\, y + a_{33} = 0$$

obtaining the coefficients $a_{11}, a_{12}, a_{22}, a_{13}, a_{23}, a_{33}$ which minimize the sum

$$S\,(a_{11}\, x^2 + 2{*}a_{12}\, x\, y + a_{22}\, y^2 + 2{*}a_{13}\, x + 2{*}a_{23}\, y + a_{33})^2$$

calculated using the coordinates x, y of the points obtained. In practice the system of linear equations is resolved with coefficients

$Sx^4, Sx^3y, Sx^2y^2, Sx^3, Sx^2y, Sx^2$

$Sx^3y, Sx^2y^2, Sxy^3, Sx^2y, Sxy^2, Sxy$

$Sx^2y^2, Sxy^3, Sx^2y, Sy^4, Sxy^2, Sy^2$

$Sx^3, Sx^2y, Sxy^2, Sx^2, Sxy, Sx$

$Sx^2y$, $Sxy^2$, $Sy^3$, $Sxy$, $Sy^2$, $Sy$

in relation to the variables $a_{11}, a_{12}, a_{22}, a_{13}, a_{23}, a_{33}$.

c) The points which are furthest from the conic section of first approximation are removed from the initial profile thus obtained, in order to eliminate erroneously inserted points, imperfections in the rim or the like from the calculation. The remaining points are then used to recalculate the conic section which best approximates them.

d) From the equation of this conic section, the spatial position of the videocamera being known, it is possible to obtain two angles which define - with respect to the reference system - the orientation of a bundle of parallel planes which intersect, in the form of a set of circles, the cone obtained, projecting into space the conic section "viewed" by the videocamera. The basic theory is that the tyre-rim edge may be always represented by a circle when viewed perpendicularly with respect to the wheel plane. In fact, the tyre-rim projects onto the videocamera an image obtained by sectioning the cone of straight lines passing through the tyre-rim and through the centre of the optical system with the plane of the videocamera. This image is a conic section. A point x', y' in the plane of the videocamera corresponds to each point of coordinates x,y in the plane of the image. Let us consider a reference system fixed to the videocamera, in which the plane of the videocamera is the plane $z=-z1$, the z axis emerges from the plane of the videocamera towards the wheel, the y axis is the vertical axis and points downwards and finally the origin of this reference system coincides with the centre of the optical system positioned opposite the videocamera.

In order to measure the toe-in: the reference system is displaced so that the new origin is the centre of the tyre-rim which, for the sake of simplicity of calculation, is considered on the z axis at a distance z0 from the videocamera lens: this transformation is represented, in homogeneous coordinates, by the matrix:

$$\begin{matrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -z0 \\ 0 & 0 & 0 & 1 \end{matrix}$$

The toe-in angle coincides with the angle through which the displaced reference system must be rotated about the y (vertical) axis so that the associated x axis lies in the wheel plane.

$$\begin{matrix} \cos(cv) & 0 & \sin(cv) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin(cv) & 0 & \cos(cv) & 0 \\ 0 & 0 & 0 & 1 \end{matrix}$$

Finally, by means of a further rotation about the x axis, the x and y axes of the new reference system lie in the wheel plane

$$\begin{matrix} 1 & 0 & 0 & 0 \\ 0 & \cos(ccv) & \sin(ccv) & 0 \\ 0 & -\sin(ccv) & \cos(ccv) & 0 \\ 0 & 0 & 0 & 1 \end{matrix}$$

In this reference system the tyre-rim has the equation: $x^2+y^2-(k*zO)^2=0$ which, in the reference system fixed to the videocamera, is equal to

$$x^2 *COS(ccv)^2*k^2*zO^2*COS(cv)^2-*zO^2(k^2-1))$$
$$-2*x*y*zO^2*(k^2-1)*SIN(ccv)*COS(ccv)*SIN(cv)$$
$$+y^2*(COS(ccv)^2*(zO^2*COS(cv)^2+zO^2*(k^2-1))-k^2*zO^2+zO^2$$
$$+2*x*zl*k^2*zO^2*SIN(cv)*COS(cv)*COS(ccv)^2$$
$$+2*y*z1*k^2*zO^2*COS(cv)*SIN(ccv)*COS(ccv)$$
$$-z1^2*COS(cv)^2*COS(ccv)^2 = 0$$

By comparison with the general form of a conic section in the plane:

$$a_{11}\, x^2 + 2*a_{12}\, x\, y + a_{22}\, y^2 + 2*a_{13}\, x + 2*a_{23}\, y + a_{33} = 0$$

it is possible to obtain cv, cvv, zl. In order simplify the calculation operation, it is convenient to convert firstly the generic conic section into a simplified canonical form:

$$b_{11}\, x^2 + b_{22}\, y^2 + b_{33} = 0$$

by performing substitution of variables

$$x = X\, COS(rr) + Y\, SIN(rr) + YO$$
$$y = -Y\, SIN(rr) + X\, COS(rr) + XO$$

where

$$rr = tg^{-1}\, (\, 2\, a_{12} / (\, a_{11}-a_{22}))\, /2$$
$$XO = (\, a_{12}\, a_{23} - a_{13}\, a_{22})\, /\, (\, a_{11}\, a_{22} - a_{12}^2)$$
$$YO = (\, a_{12}\, a_{13} - a_{13}\, a_{11})\, /\, (\, a_{11}\, a_{22} - a_{12}^2)$$

therefore

$$b_{11} = (a_{11}-a_{22})*COS(rr)^2-2*a_{12}*SIN(rr)*COS(rr)+a_{22}$$
$$b_{22} = (a_{22}-a_{11})*COS(rr)^2+2*a_{12}*SIN(rr)*COS(rr)+a_{11}$$

in the new reference system.

In particular

$rr = \tan^{-1}( SIN(cv)*COS(CCV)/SIN(CCV) )$

which depends only on cv, cvv and not on the spatial position of the wheel. The coordinates X0, Y0 are not used, depending on the relative position of videocamera and wheel, not being relevant for the calculation of the toe-in values.

The coefficients of the canonical conic section are

$b_{11} = z0^2 * COS(cv)^2*\cos(ccv)^2$

$b_{22} = k^2*z0^2*COS(cv)^2*COS(CCV)^2-z0^2*(k^2-1)$

$b_{33} = -k^2*z0^2*z1^2*COS(cv)^2*COS(ccv)^2/$
$(k^2*COS(cv)^2*COS(ccv)^2-k^2+1)$

The ratio $b_{22}/b_{11}$ does not depend on z0 (distance between videocamera/wheel), but only on z1 (focal length of videocamera) and on k (which defines the apparent radius, i.e. the radius of the wheel in relation to the distance).

In fact:

$b_{22}/b_{11} = (1-k^2)/(COS(ccv)^2COS(cv)^2)+k^2.$

Moreover, $b_{33}*b_{22}/b_{11} = -k^2*z0^2*z1^2$, once z1 is known, indicates the value of k*z0 and defines completely the set of circles, the projection of which onto the plane of the videocamera is the conic section determined. Using $b_{11}/b_{33}$, $b_{22}/b_{33}$ and rr, there are three equations in three unknown values ( k*z0, cv, ccv ) which identify a bundle of parallel planes in which the rim may lie.

The angles thus obtained are adequate for determining total toe-in and camber.

2) Measurement of the toe-in of the individual wheels and other set-up angles of the motor vehicle

As already briefly mentioned, the measurements obtained as described in the previous section are not sufficient for calculation of the toe-in values of the individual wheels, the thrust angle and the set-back angle, for which it is further required to determine the position of the vehicle with respect to the spatial system comprising a fixed reference quadrilateral. For this purpose the spatial position of the wheel and the vehicle are therefore determined.

In order to determine this position, distance measurements are required so as to identify precisely, on each of the wheels, a point which has a precise correlation with that plane - among the bundle of planes determined in the previous section - which contains the tyre-rim profile, as identified with the videocamera.

According to the present invention, the system for determining this distance consists in using the image of the wheel: more precisely, the apparent radius of the rim is obtained geometrically from the conic equation which represents the tyre-rim profile in the plane of the videocamera. From the analysis carried out in the previous section, the coefficient k*z0 is obtained, said coefficient identifying the apparent radius of the rim. If it is considered that the four wheels of the vehicle must have the same identical rim, it is obvious that their ideal radius - except for the manufacturing tolerances of the said rims - is the same; however, the real radius and the apparent radius are associated by the relation:

$$ra/rr = dlc/df$$

where ra = apparent radius, rr = real radius, dlc = distance of the videocamera lens from the wheel rim, df = focal length of the videocamera lens. If we now assume that

$$ra = rr$$

and taking into account that df is known, it is possible, from the apparent radius measured for each wheel, to obtain the distance dlc, namely the distance from the videocamera, or the fixed reference quadrilateral, of the plane which contains the wheel rim. In order to verify the assumption regarding the value to be assigned to the apparent radius it is possible (but not necessary for correct measurement) to compare the real radius value with the true value, which is available for example in a data base relating to the wheel type used for the vehicle being tested.

The manufacturing tolerances of the rims influence the calculation precision of the distances and this in turn influences the calculation of the thrust axis and the set-back value; if the distance between videocamera and rim is for example 500 mm and the radius of the rims is 200 mm, every mm of tolerance in this radius corresponds to an error of 2.5 mm in the distance measurement. For a vehicle with a wheel base of 2000 mm, this error is equivalent to a an angular error of 5° in the measurement of the thrust axis and the set-back value. Such an error is certainly acceptable for measurements performed during normal checking of motor vehicles.

3) Calibration

The system envisages a calibration procedure which consists of two separate and successive steps

1. Correction of the non-linearity of the optical system: in order to ensure the required measuring precision, the ever-present distortion caused by the optical

system must be compensated for. This distortion, if it is not corrected, produces a deformation of the conic section and therefore a measuring error. In order to correct the distortion, the image of a grid is recorded and the position of the points on the grid is determined: knowing the position which these points should theoretically have, it is possible to correct the distortion thereof.

2. Correction of the position of the videocameras in the measuring position: in order to be able to carry out correct measurements, the relative position of the various videocameras in the fixed spatial reference system must be known. This calibration is performed by measuring the characteristic angles of a specially designed calibration apparatus: these characteristic angles are then subtracted from the angles measured.

It is understood, however, that the invention must not be regarded as limited to the particular embodiment illustrated above which constitutes only a non-limiting example of the scope of the invention, but that various variants are possible, all of which within the scope of a person skilled in the art, without thereby departing from the scope of protection of the said invention, as defined by the claims which follow.

## CLAIMS

1) Method for checking the set-up of the suspension of motor vehicles, in particular for measuring the total toe-in and camber angles of the wheels, of the type in which at least two detecting videocameras in predetermined fixed positions are used, said videocameras being able to define a fixed spatial reference system, these videocameras being associated with at least two respective opposite wheels of a same axle of the vehicle, characterized in that it comprises the steps of:

- identifying, for each wheel, the profile of a rim associated with the wheel and projected onto the optical sensor plane of the respective videocamera, as the locus of the points of greatest variation in luminous intensity;

- calculating mathematically, using a repeated approximation method, the conic section which best approximates the profile thus obtained;

- calculating, from the equation of this conic section and from the known coordinates of the position of the videocamera in the fixed spatial reference system, the two angles which define - with respect to a vertical longitudinal plane and with respect to a horizontal plane of the fixed reference system - the orientation of a bundle of parallel planes which intersect, in the form of a set of circles, the cone obtained, projecting into space the conic section "viewed" by the videocamera, these angles representing the total toe-in and the camber of the wheel, respectively.

2) Method for checking the set-up of the suspension of motor vehicles according to Claim 1, in particular for measuring the toe-in angles of the individual wheels as well as other set-up angles of the vehicle, characterized in that it comprises moreover the steps of:

- determining the distance of each individual wheel from the respective videocamera by means of a comparison of the individual apparent radiuses of the different wheels detected, based on the assumption that the respective rims all have the same real radius;

- defining, on the basis of the positions of the videocameras in the fixed spatial reference system and their distance from the individual wheels, also the position of the vehicle and its main longitudinal axis in said space; and

- calculating the toe-in angle of the individual wheels and the other set-up angles, placing said total toe-in angle in relationship with a vertical plane passing through said longitudinal axis.

3) Method for checking the set-up of the suspension of motor vehicles

according to Claim 1, characterized in that said repeated approximation method consists in the least square fit mathematical method.

4) Method according to Claims 1, 2 or 3, characterized in that said spatial reference system consists of a fixed quadrilateral, taking the physical form of the fixed position of four videocameras, one being located opposite each wheel of a four-wheel vehicle.

5) Method according to Claim 4, characterized in that each of said videocameras is oriented so as to view the respective wheel at an oblique angle.

6) Method according to Claims 1, 2 or 3, characterized in that said locus of the points of greatest variation in luminous intensity is defined at the transition from the wheel rim to the tyre.

7) Method according to Claim 6, characterized in that the image recorded by each videocamera is digitalized and converted into a first rectangular matrix of intensity values, one for each digitalized point.

8) Method according to Claim 7, characterized in that said matrix of values is equalized, in order to reduce the effect of variation in the lighting conditions of the object.

9) Method according to Claim 8, characterized in that a mathematical operator (Laplace, Sobel) is applied to the equalized values of said matrix so as to obtain a new matrix of values representing the gradient of variation in intensity.

10) Method according to Claim 9, characterized in that a threshold operator is used in order to extract from the image recorded by the videocamera only those gradient values which exceed a predefined threshold in order to obtain a second binary reference matrix.

11) Method according to Claim 10, characterized in that said second reference matrix is filtered using an erosion operator so as to eliminate the isolated points and leave only those belonging to defined geometric groups (lines, circles, conic section, etc.).

12) Method according to Claim 6, characterized in that each wheel is illuminated with infrared light, and an infrared filter having spectral characteristics coinciding with said infrared light is placed in front of the optical system of each respective videocamera.

13) Method according to Claim 12, characterized in that the image to be processed is obtained as the difference between a first image detected with the infrared lighting switched on and a second image detected with the infrared light-

ing switched off.

14) Method according to Claim 1, 2 or 3, characterized in that a pair of coordinates ( x, y ) corresponding to the position of the point in the image plane is assigned to each point and the equation conic is identified as follows:

$$a_{11} x^2 + 2*a_{12} x y + a_{22} y^2 + 2*a_{13} x + 2*a_{23} y + a_{33} = 0$$

determining the coefficients $a_{11}, a_{12}, a_{22}, a_{13}, a_{23}, a_{33}$ which minimize the sum S $(a_{11} x^2 + 2*a_{12} x y + a_{22} y^2 + 2*a_{13} x + 2*a_{23} y + a_{33})^2$ calculated using the coordinates x, y of the points obtained.

15) Method according to Claim 14, characterized in that, from the initial conic section profile thus obtained, the points which are furthest from the conic section of first approximation are removed in order to eliminate from the calculation erroneously inserted points, imperfections in the rim or the like, and the remaining points are used to recalculate the conic section which best approximates them.

16) Method according to Claims 1, 2 or 3, characterized in that the determination of the distance of each individual wheel from the respective videocamera, by means of comparison between the apparent radius of the different wheels detected, is performed on the basis of the relation:

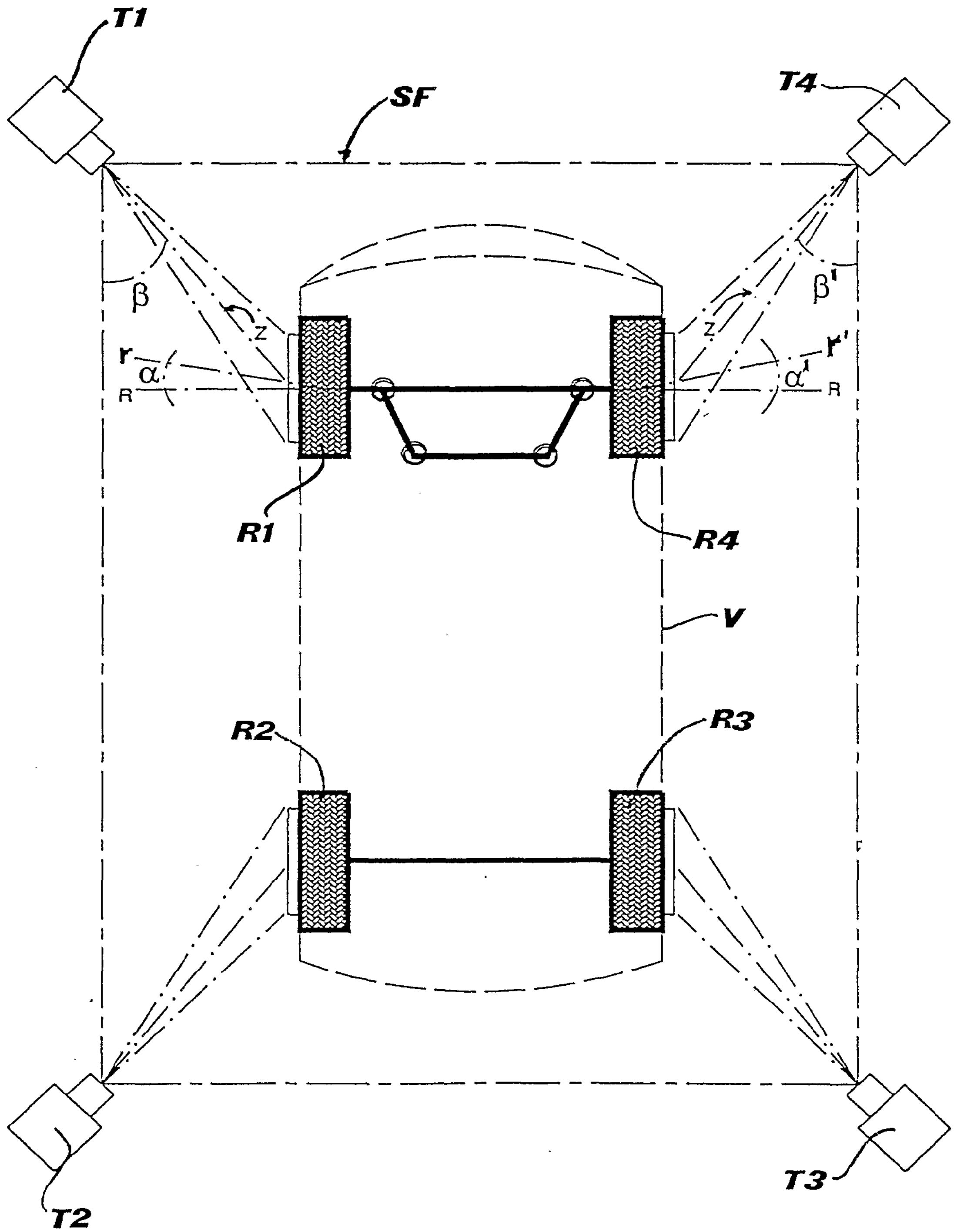
ra/rr = dlc/df

where ra = apparent radius, rr = real radius, dlc = distance of the videocamera lens from the wheel rim and df = focal length of the videocamera lens, on the assumption that:

ra = rr

and taking into account the fact that df is known.

17) Method according to Claims 16, characterized in that the real radius (rr) is moreover compared to the true value of the radius of the rim, available in a data base.


T1
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# INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB 01/00613

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 7 G01B11/275 G06T1/00

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | DE 29 48 573 A (SIEMENS) 4 June 1981 (1981-06-04) cited in the application claim 1 | 1 |
| A | EP 0 803 703 A (GSS) 29 October 1997 (1997-10-29) claim 1 | 1 |
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☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 11 July 2001 | 02/10/2001 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL – 2280 HV Rijswijk<br>Tel. (+31–70) 340–2040, Tx. 31 651 epo nl,<br>Fax: (+31–70) 340–3016 | Mielke, W |

# INTERNATIONAL SEARCH REPORT

**Information on patent family members**

| International Application No |
|---|
| PCT/IB 01/00613 |

| Patent document cited in search report | | Publication date | Patent family member(s) | | Publication date |
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